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ABSTRACT

Suggestions for instructional improvement are offered to science teachers in this compilation of research summaries which addresses specific areas of science education. This series examines the topic areas of: (1) computer use in science instruction (reviewing five categories of computer use which focus on the learner); (2) the role of the laboratory in science teaching (providing theoretical perspectives and research findings which support the use of laboratory instruction); (3) females in science courses and careers (discussing significant factors for encouraging females in the sciences and also listing do's and don'ts for fostering equity); and (4) question usage in science classrooms (examining the types and purposes of teacher questions and suggesting ways for improving questioning behavior). (ML)

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RESEARCH MATTERS...TO THE SCIENCE TEACHER

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Rod Doran, Editor

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Research Matters . . . To The Science Teacher

COMPUTER USE IN SCIENCE INSTRUCTION

By Robert D. Sherwood

Methods of Computer Use

There are several ways that computers can be effectively used in science instruction. A variety of terms have been used to indicate these methods. In this paper, the five categories of use focus on the learner rather than the technology:

- (1) *Learning From Computers.* The computer is utilized as a dispenser of information or a tester of student ability. The types of software used with this role include tutorial and drill and practice programs.
- (2) *Learning With Computers.* The computer takes the role of a "partner" with the student. Computer software used with this role is usually of the simulation, game or data collection type where direct instruction is not emphasized, rather the student has an opportunity to work in alternative environments to those of regular classroom setting.
- (3) *Learning About Computers.* The focus is on instruction about the operation, use and programming of computer systems.
- (4) *Learning About Thinking with Computers.* The computer is used to assist in developing reasoning and problem solving skills in students. Computer languages such as Logo and "problem solving" software are associated with this use.
- (5) *Managing learning with Computers.* Computers can be used to assist teachers in the management of instruction through storing student test scores, computing class averages and grades, and calculating summary statistics for the teacher.

The emphasis on inquiry approaches to science would seem to favor the use of the computer in the "Learning With" role mentioned above. Recent software developments allow students to investigate in ways that are not available in normal classrooms. Examples include software that allows (a) simulated genetic manipulations over long time periods, and (b) experiments that are not feasible in classrooms such as high temperature and pressure chemical reactions and experiments in physics that investigate alternatives to Newtonian mechanics.

Another aspect of the "Learning With" role is that of using the computer in data collection. Data collection by computer allows increased precision in measurements as well as assisting the student in data manipulation and graphing.

Research Results

Research conducted across many content areas and various uses of computers has provided the fol-

lowing generalities:

- When Computer Based Instruction (CBI) and traditional instruction are compared, student *achievement* in the CBI group is equal or better than the traditional group.
- When CBI and traditional instruction are compared, equal or better achievement using CBI is obtained in *less time*.
- The use of CBI improves student *attitudes* toward the use of computers in learning situations.
- "Primary CBI", where no teacher interaction occurs during the learning process, is much less effective than "adjunct CBI" where *teacher interaction* is a critical part of the instruction.
- While advocates of teaching computer *programming* claim that programming will result in higher level cognitive skills and greater achievement there is little support on this claim.
- Tutorial and drill modes seem to be more effective for *low-ability* students than for middle or high-ability students.
- The CBI effect on achievement seems to be greatest for pre-college age learners.

While these results are generally positive, the research to date does *not* show large benefits in terms of CBI considering the economics. Modest increases in achievement from CBI have often been the result of expensive operations. As more powerful hardware and software become less expensive, this pattern may change.

Additionally, much of the early research has centered around large main frame computers utilizing software of the "Learning From" role, e.g., drill and practice and tutorial programs. Further, the achievement measures for these experiments have focused on short term learning with information about long term retention seldom collected.

Research Related to Science Instruction

In science education, considerable research has been conducted on the use of computers, and more recently microcomputers. Many of these studies have examined simulation activities to augment or extend laboratory situations. Overall, the same type of results that were mentioned above holds for science instruction. Generally, one finds equal or greater achievement for the CBI situations, less time spent to produce similar achievement levels and improved student attitudes have been found.

The role of the instructor is an area where work has also been done in relation to science instruction. Preliminary studies seem to indicate that the teacher's role is crucial for successful implementation of CBI instruction. Students who work with CBI situations in total class settings, directed by a teacher, appear to have higher achievement than those who work in smaller groups without teacher intervention. This would indicate that the combination of computer interaction and a well trained teacher may be a very effective method of instruction.

Dr. Robert D. Sherwood is Assistant Professor of Education and Associate Director of the Learning Technology Center, Peabody College of Vanderbilt University. He is a member of the National Association For Research in Science Teaching, an organization that seeks to improve science teaching through research.

For more information and specific references, write to Dr. Sherwood at Box 45, Peabody Station, Vanderbilt University, Nashville, Tennessee 37203.

Research Matters . . . To The Science Teacher

THE ROLE OF THE LABORATORY IN SCIENCE TEACHING

By Patricia E. Blosser

Science educators have believed that the laboratory is an important means of instruction in science since late in the 19th century. Laboratory activities were used in high school chemistry in the 1880s (Fay, 1931). In 1886, Harvard University published a list of physics experiments that were to be included in high school physics classes for students who wished to enroll at Harvard (Moyer, 1976). Laboratory instruction was considered essential because it provided training in observation, supplied detailed information, and aroused pupils' interest. These same reasons are still accepted almost 100 years later.

Shulman and Tamir, in the *Second Handbook of Research on Teaching* (Travers, ed., 1973), listed five groups of objectives that may be achieved through the use of the laboratory in science classes:

- (1) skills — manipulative, inquiry, investigative, organizational, communicative
- (2) concepts — for example, hypothesis, theoretical model, taxonomic category
- (3) cognitive abilities — critical thinking, problem solving, application, analysis, synthesis
- (4) understanding the nature of science — scientific enterprise, scientists and how they work, existence of a multiplicity of scientific methods, interrelationships between science and technology and among the various disciplines of science
- (5) attitudes — for example, curiosity, interest, risk taking, objectivity, precision, confidence, perseverance, satisfaction, responsibility, consensus, collaboration, and liking science (1973:1119).

Writing about laboratory teaching at the college level, McKeachie said:

Laboratory teaching assumes that first-hand experience in observation and manipulation of the materials of science is superior to other methods of developing understanding and appreciation. Laboratory training is also frequently used to develop skills necessary for more advanced study or research.

From the standpoint of theory, the activity of the student, the sensorimotor nature of the experience, and the individualization of laboratory instruction should contribute positively to learning. Information cannot usually be obtained, however, by direct experience as rapidly as it can from abstractions presented orally or in print... Thus, one would not expect laboratory teaching to have an advantage over other teaching methods in the amount of information retention, in ability to apply learning, or in actual skill in observation or manipulation of materials... (in Gage, 1963:1144-1145).

Another writer, Pickering (1980), identified two misconceptions about the use of the laboratory in college science. One is that laboratories somehow "illustrate" lecture courses — a function that (in Pickering's opinion) is not possible in a simple, one-afternoon exercise. Pickering contended that most scientific theories are based on a large number of very sophisticated experiments. He suggested that, if lecture topics are to be illustrated, this should be done through the use of audio-visual aids or demonstrations. The second misconception is that laboratories exist to teach manipulative skills. Pickering argued that the majority of students in science laboratory classes do not have a career goal of becoming a professional scientist. Further, many of the skills students learn in laboratories are obsolete in science careers. If these skills are worth teaching, it is as tools to be mastered for basic scientific inquiry and not as ends in themselves (1980:80).

Research Findings

Science educators frequently turn to the research literature for support of their requests for funds for supplies and equipment for laboratory activities. Science education researchers have examined the role of the laboratory on many variables, including achievement, attitudes, critical thinking, cognitive style, understanding science, the development of science process skills, manipulative skills, interests, retention in science courses, and the ability to do independent work.

Many of these studies contain the finding of "no significant differences" between groups. In 1978 the National Science Teachers Association produced the first volume of its series *What Research Says to the Science Teacher*. One of the chapters in this volume was on the role of the laboratory in secondary school science programs. Gary C. Bates reviewed 82 studies and concluded that "...the answer has not yet been conclusively found..." to the question: What does the laboratory accomplish that could not be accomplished as well by less expensive and less time consuming alternatives? (in Rowe, ed., 1978:75).

A number of possible explanations exist for this discouraging conclusion. Much of the research comes from doctoral studies which are usually first attempts at research. Very few studies include a follow-up of the subjects involved to see if there were any changes other than those tested for at the end of the study. Many of the investigations are of the comparative variety (approach X vs. a "lab" approach). Often these instructional approaches are not described in sufficient detail for the reader to be able to judge the value of the study.

As McKeachie pointed out, laboratory teaching may not be the best method to choose if one's objective is to have students retain information. However, the need for "educational accountability" has been translated into the need to increase test scores. Some of the outcomes of a "lab approach" are difficult to test in a multiple-choice test.

Some-Positive Findings

Positive research findings on the role of the laboratory in science teaching do exist. Laboratory activities appear to be helpful for students rated as medium to low in achievement on pretest measures (Boghai, 1979; Grozier, 1969). Godomsky (1971) reported that laboratory instruction increased students' problem-solving ability in physical chemistry and that the laboratory could be a valuable instructional technique in chemistry if experiments were genuine problems without explicit directions. Working with older, disadvantaged students in a laboratory setting, researchers (McKinnon, 1976; McDermott et al., 1980) used activities designed to create disequilibrium in order to encourage cognitive development.

Some Final Comments

No space has been allocated in this discussion of the role of the laboratory to the approach involved: inquiry vs. verification. It has been assumed that proponents of laboratory activities are interested in having students inquire and in having them work with concrete objects. Comber and Keeves (1973) found, when studying science education in 19 countries, that in six countries where 10-year-old students made observations and did experiments in their schools, the level of achievement in science was higher than in schools where students did not perform these activities.

A modern research technique is meta-analysis—in which a group of studies is analyzed for similarities and differences in findings related to their common thrust. A meta-analysis on the effects of various instructional techniques (Wise and Okey, 1983) was focused on 12 teaching strategies. Two of these 12 were related to the laboratory approach: inquiry-discovery and manipulative. Although these two strategies did not exhibit as large an effect as did the strategies of focusing and questioning, there was some positive support for inquiry teaching. An effective science classroom was characterized as one in which students had opportunities to physically interact with instructional materials and engage in varied kinds of activities (1983:434). Lott (1983) reported on a meta-analysis of the effect of inquiry (inductive) teaching and advance organizers in science education. Lott wrote that the inductive approach appeared to be more useful (than the deductive) in those situations where high levels of thought, learning experiences, and outcome demands were placed upon subjects (1983:445).

Science educators at all levels need to continue to study the role of the laboratory in science teaching. However, perhaps the question we should be asking is not "What is the laboratory better than?" but "For what purposes should the laboratory be used, under what conditions, and with what students?"

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Dr. Patricia E. Blosser is Professor of Science Education at the Ohio State University and Associate Director of the ERIC Clearinghouse for Science, Mathematics and Experimental Education. She is a member of the National Association for Research in Science Teaching, an organization that seeks to improve science teaching through research.

For further information, contact Dr. Blosser at Science and Mathematics Education, the Ohio State University, Columbus, Ohio 43210.

Research Matters . . . To The Science Teacher

ENCOURAGING GIRLS IN SCIENCE COURSES AND CAREERS

By Jane Butler Mahle

In the United States women comprise approximately 50% of the work force, yet only 9% are employed as scientists and engineers. Factors contributing to this situation have been analyzed in research studies. Explanations have ranged from differences in spatial ability related to a sex-linked gene to differences in early childhood toys and games. One study reported a dramatic decline in positive attitudes toward science as girls mature. The authors attribute this decline to startling inequities in the number of science activities experienced by males and females in elementary and secondary classrooms. In addition, the analysis of the results from the 1981-82 National Assessment of Educational Progress science study indicate that girls continue to score below the national mean on all science achievement items and to express negative attitudes toward science. Although societal, educational, and personal factors are all involved, differences within the science classroom may be a contributing factor to low interest of women in science and scientific careers.

However some girls like science and continue to study science. In order to determine what motivates these girls to pursue science courses and careers, a group of researchers conducted nationwide surveys to identify teachers who have motivated high school girls to continue in science. In addition to assessing instructional techniques, classroom climate, and teacher-student interactions, a selected sample of students (former and current) responded to questionnaires which assessed attitudes, intellectual and socio-cultural variables.

Two types of research, observational and survey, were used to gather data for this project. The case studies, which were the observational part of this project, provided information about the student-teacher and student-student interactions. Case studies are limited in the extent to which they may produce generalizations applicable to other situations. Therefore, they were supplemented with survey data, describing the abilities, activities, and aspirations of the involved students and teachers. These research efforts led to the following conclusions.

Teachers who successfully *encourage* girls in science:

- Maintain well-equipped, organized, and perceptually stimulating classrooms.
- Are supported in their teaching activities by the parents of their students and are respected by current and former students.
- Use non-sexist language and examples and include information on women scientists.

- Use laboratories, discussions, and weekly quizzes as their primary modes of instruction and supplement those activities with field trips and guest speakers.

- Stress creativity and basic skills and provide career information.

Factors which *discourage* girls in science:

- High school counselors who do *not* encourage further courses in science and mathematics.
- Lack of information about science-related career opportunities and their prerequisites.
- Sex-stereotyped views of science and scientists which are projected by texts, media, and many adults.
- Lack of development of spatial ability skills (which could be fostered in shop and mechanical drawing classes).
- Fewer experiences with science activities and equipment which are stereotyped as masculine (mechanics, electricity, astronomy).

The teachers, both male and female, who were successful in motivating girls to continue to study science practiced "directed intervention." That is, girls were asked to assist with demonstrations; were required to perform, not merely record, in the laboratories; and were encouraged to participate in science-related field trips. In addition, teachers stressed the utility of math and science for future careers.

Both male and female students in the schools identified as "positive toward girls in science" were questioned about their attitudes toward science and science careers. When compared with a national sample, the students in these schools had a much more positive outlook. This difference was especially pronounced among girls. When asked how frequently they like to attend science class, 67% of the girls responded "often," compared with 32% of the girls in the national sample. And when asked if they would like to pursue a science-related job, 65% of the girls said "yes," compared with 32% of the girls in the national sample.

This research suggests that teaching styles and other school-related factors are important in encouraging girls as well as boys to continue in science courses and careers. The path to a scientific career begins in high school and requires skilled and sensitive teachers. This research identified the following "Do's" and "Don't's" for teachers who want to foster equity in science classrooms.

DO

- use laboratory and discussion activities
- provide career information
- directly involve girls in science activities
- provide informal academic counseling
- demonstrate unisex treatment in science classrooms

DON'T

- use sexist humor

- use sex-stereotyped examples
 - distribute sexist classroom materials
 - allow boys to dominate discussions or activities
 - allow girls to passively resist
-

Dr. Jane Butler Kahle is Professor of Biological Sciences and Education and Associate Dean of the Graduate School at Purdue University, West Lafayette, Indiana. She is a member of the National Association for Research in Science Teaching, an organization that seeks to improve science teaching through research.

This research is described in a monograph available from the author and in a book, *Women in Science: A Report From the Field*, Falmer Press, available summer 1985. For further information contact: Dr. J.B. Kahle, 221 CHEM, Purdue University, W. Lafayette, Indiana 47907.

Research Matters . . . To The Science Teacher

USING QUESTIONS IN SCIENCE CLASSROOMS

By Patricia E. Blosser

One objective of science teaching is the development of higher level thinking processes in students. To achieve this objective, teachers need to facilitate communication with and among students. One of the methods for encouraging students to communicate is to ask them questions. Teacher questions can serve a variety of purposes:

- to manage the classroom ("Have you finished the titration?" "How many have completed problem 17?")
- to reinforce a fact or concept ("The food making process in green plants is called photosynthesis, right?")
- to stimulate thinking ("What would happen if . . .?")
- to arouse interest
- to help students develop a mind-set.

Any teacher can create his/her own list of additional functions questions can serve.

Science teachers are concerned about helping students to become critical thinkers, problem solvers, and scientifically literate citizens. If we want students to function as independent thinkers, we need to provide opportunities in our science classes that allow for greater student involvement and initiative and less teacher domination of the learning process. This means a shift in teacher role from that of information-giver to that of a facilitator and guide of the learning process.

Central to this shift in teacher role are the types of questions that teachers ask. Questions that require students to recall data or facts have a different impact on pupils than questions which encourage pupils to process and interpret data in a variety of ways.

The differential effects of various types of teacher questions seem obvious, but what goes on in classrooms? In one review of observational studies of teacher questioning, spanning 1893-1963, it was reported that the central focus of all teacher questioning activity appeared to be the textbook. Teachers appeared to consider their job to be to see that students have studied the text. Similar findings have been reported from observational studies of teachers' questioning styles in science classrooms. Science teachers appear to function primarily at the "recall" level in the questions they ask, whether the science lessons are being taught to elementary students or secondary school pupils.

Why doesn't questioning behavior match educational objectives? One hypothesis is that teachers are not aware of their customary questioning patterns. One way to test this hypothesis is to use a question analysis system. One commonly-used

system is that of Bloom's taxonomy of educational objectives, ranging from knowledge to evaluation. Other systems categorize questions as higher-order or lower-order. Lower-order questions are those of cognitive-memory thinking and higher-order questions involve convergent thinking, divergent thinking, or evaluative thinking.

Blosser developed a category system for questions used in science lessons. In this system, questions are initially classified as:

Closed . . . limited number of acceptable responses

Open . . . greater number of acceptable responses

Managerial facilitate classroom operations

Rhetorical re-emphasize, reinforce a point

Questions which are classified as being either Open or Closed can be further classified relative to the type of thinking stimulated: cognitive-memory or convergent for Closed Questions and divergent or evaluative thinking for Open Questions. This system has been used successfully with both pre-service and in-service science teachers to help them analyze their questioning behavior.

Investigations have been conducted to see if pre-service teachers could improve their questioning behavior through question analysis. From these studies, it has been concluded that the use of models (audio, video) is helpful, that skill in the use of science processes appears to be related to the complexity of questions asked, that the use of a question category system can be learned, and that the number of divergent and evaluative questions asked in lessons can be increased.

Research involving in-service teachers has produced mixed results. When in-service teachers learned to use questions at different levels of complexity, their students achieved at a higher level than did pupils of teachers asking only low-level questions. In-service teachers who experienced instructional modules designed to improve their questioning skills asked a wider variety of questions. However, some teachers found it difficult to allocate time to working with the modules provided.

Teachers who want to improve their questioning behavior (e.g. ask a wider variety of questions) can do several things. They need to locate a question category system they can use comfortably and then apply it, during lesson planning and in post-lesson analysis. Because of the variety of things that go on during a lesson, a post-lesson analysis is best accomplished by tape-recording the lesson or at least those parts of the lesson containing the most teacher questions. Start with the class in which the lesson and activities seem to flow most smoothly. After getting accustomed to hearing yourself and analyzing the questions you ask, tape your problem class(es). Are the kinds of questions you ask and the context in which you ask them different in these classes? Are some patterns of teacher-student interaction more effective (than others) for you?

Don't forget about the value of written questions as

well as oral ones. If a teacher's oral questioning behavior involves using a variety of question types and promotes different levels of thinking, so should quiz and test questions. Students quickly determine what the teacher values by the type of questions used to formulate their grade.

The kinds of questions science teachers ask, the interaction strategies they use, and the students of whom they ask questions have not been the focus of many science education studies. The cognitive aspects of questions have been researched more than have the affective aspects. More collaborative (school-university) research needs to be done on the impact of questions on students' attitudes toward science and science classes. The following questions are worthy of consideration. Do science teachers customarily direct higher-level questions to their more able students? Do they distribute the opportunity to respond equally among students of different ability levels, and of different social and cultural backgrounds and between male and female students? Do

teachers react differently to similar responses from different students? Are some communication strategies more effective than others for promoting student participation and thinking? What kinds of questions do students ask?

Dr. Patricia E. Blosser is Professor of Science Education at the Ohio State University and Associate Director of the ERIC Clearinghouse for Science, Mathematics and Experimental Education. She is a member of the National Association for Research in Science Teaching, an organization that seeks to improve science teaching through research.

For further information, contact Dr. Blosser at Science and Mathematics Education, the Ohio State University, Columbus, Ohio 43210.